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GEODETIC SATELLITE RESULTS FOR DEEP SPACE STATION COORDINATES

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GSFC — GODDARD SPACE FLIGHT CENTER
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DEEP SPACE STATION COORDINATES

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ABSTRACT

Deep Space Station (DSS) coordinates inferred from near earth satellite solutions for nearby optical and U.S. Navy Doppler tracking sites derived by Goddard Space Flight Center (GSFC), the Smithsonian Astrophysical Observatory (SAO) and the Naval Weapons Laboratory (NWL) are compared to those obtained by JPL from tracking of deep space vehicles. Comparisons of results for longitude differences and spin axis distances show especially close agreement between JPL and GSFC optical results, although agreement is very good for all the various solutions. Exceptions are at stations 4712 (Goldstone) and 4742 (Tidbinbilla, Aus.). In the case of Goldstone, the spin axis distance obtained from the coordinates for the nearby doppler station (737) disagrees by about 30m from the other solutions. At Tidbinbilla, there is an inconsistency of about 10m between the GSFC optical and the other solutions that suggests survey error. However, the general agreement indicates that an accuracy of 5m or better in each coordinate has been obtained by GSFC optical satellite solutions. New DSS site coordinates based

on GSFC optical solutions alone, and determined from combined JPL DSS-GSFC optical results are also given.

The results of these comparisons show that the GEOS-I and II optical flash data have yielded results equal or superior to those of other systems.

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1. INTRODUCTION

In any data analysis effort, evaluation of the results is one of the most difficult and important tasks. Internal consistency is usually easy to demonstrate, but systematic errors are often more important than errors introduced by random uncertainty of data. In satellite geodesy, it is useful to compare the results of several investigators, but in many cases the solutions are not truly independent. Fortunately, the results of JPL for spin-axis distance and longitude difference are both highly accurate and are obtained independently of near Earth satellites. Thus the agreement that now exists between Earth satellite and JPL solutions is highly satisfying. We can have confidence that satellite solutions for station coordinates based on optical flash data can produce positions to an accuracy of 5m or better in each coordinate.

2. DEEP SPACE STATION (DSS) COORDINATES

As noted by Mottinger,[1] DSS data from interplanetary spacecraft do not yield a complete station position. The well-determined parameters are the distance of a station from the Earth's spin-axis and the relative longitudes of stations. The Earth-Fixed Z component of station position is poorly determined. Thus complete DSS positions rely on independent determinations.

In no case is an optical or doppler station precisely contiguous with a DSS site. However, as seen in Table 1, in all cases the stations are very close, so close

Table 1

Local Geodetic Coordinates[1] for Nearby Optical, Doppler, and DSS Stations

Location (Instrument)	Number	Datum	Latitude (N)	Longitude (E)	MSL Height (m)	Ellipsoidal Height (m)
Goldstone, California (MOTS)	1030	NAD*	35°19'48".088	243°06'02".730	929.1	907.1
Rosamund, California (Baker-Nunn)	9113	NAD	34°57'50".742	242°05'11".584	784.2	760.2
Goldstone, California (DSS)	4712	NAD	35°17'59".854	243°11'43".414	988.9	966.9
Goldstone, California (Doppler)	737	NAD	35°18'10".960	243°12'54".060		1028.0
Woomera, Australia (MOTS)	1024	AGD†	-31°23'30".069	136°52'11".022	132.8	133.8
Woomera, Australia (Baker-Nunn)	9023	AGD	-31°23'30".816	136°52'39".016	141.2	142.2
Woomera, Australia (DSS)	4741	AGD	-31°22'59".431	136°53'10".124	151.6	152.6
Woomera, Australia (Doppler)	743	AGD	-31°23'30".610	136°52'37".890		143.6
Orroral, Australia (MOTS)	1038	AGD	-35°37'37".501	148°57'10".705	931.6	937.6
Tidbinbilla, Australia (DSS)	4742	AGD	-35°24'08".038	148°58'48".206	655.0	661.0
Tidbinbilla, Australia (Doppler)	749	AGD	-35°24'18".360	148°58'52".760		652.3
Johannesburg, Republic of South Africa (MOTS)	1031	ARC	-25°52'58".862	27°42'27".931	1522.3	
Olifantsfontein, Republic of South Africa (Baker-Nunn)	9002	ARC	-25°57'33".850	28°14'53".910	1544.0	
Johannesburg, Republic of South Africa (DSS)	4751	ARC	-25°53'21".150	27°41'08".530	1391.0	

*North American Datum

†Australian Geodetic Datum

[1] From Reference 9.

Table 2

Coordinates Referred to a Center of Mass System Used in Analysis

Experimenter	Location	Number	Latitude	E. Longitude	Ellipsoidal Height (m)
GSFC[2]	Goldstone, California	1030	35°19'47".894	243°05'58".916	876.3
SAO[3]	Rosamund, California	9113	34°57'50".568	242°05'07".538	743.4
NWL[4]	Goldstone, California	737	35°18'10".99	243°12'49".22	957.0
GSFC[1]	Woomera, Australia	1024	-31°23'25".883	136°52'15".137	129.8
SAO[3]	Woomera, Australia	9023	-31°23'26".821	136°52'43".327	134.3
NWL[4]	Woomera, Australia	743	-31°23'25".62	136°52'41".26	127.0
GSFC[1]	Orroral, Australia	1038	-35°37'32".682	148°57'14".850	949.6
NWL[4]	Tidbinbilla, Australia	749	-35°24'12".97	148°58'55".58	644.2
GSFC[1]	Johannesburg, Rep. of S. Afr.	1031	-25°53'01".440	27°42'26".208	1541.0
SAO[3]	Olifantsfontein, Rep. of S. Afr.	9002	-25°57'36".596	28°14'52".309	1556.9

[1]Reference 2

[2]Reference 8

[3]Reference 3

[4]Reference 4

<u>Reference Spheroids</u>

GSFC and SAO	Semi-major axis = 6378155 meters 1/flattening = 298.255
NWL - Goldstone	Semi-major axis = 6378166 meters 1/flattening = 298.3
NWL - Woomera and Tidbinbilla	Semi-major axis = 6378160 meters 1/flattening = 298.25

that significant survey error can generally be regarded as unlikely. However, as is discussed in the following sections, a problem may exist with the survey for the Minitrack Optical Tracking System (MOTS) at Orroral, Australia.

The procedure used to obtain DSS coordinates from the GSFC[2], SAO[3], and Naval Weapons Laboratory (NWL)[4] satellite solutions (given in Table 2) is as follows. The local-to-center of mass shift in each Cartesian coordinate of the nearby satellite tracking station was calculated and then applied to the local coordinates of the DSS. The resulting derived DSS coordinates were then used to calculate spin-axis distances and longitude differences. A comparison of the spin-axis distances is given in Table 3 for the JPL, GSFC, SAO and NWL solutions.

The agreement is very good, with the exception of the NWL result for Goldstone. The close agreement of the GSFC and JPL results also suggests that the height disagreement between GSFC and SAO noted in[6] may be largely due to error in the SAO-determined heights. Regardless, if the NWL result for Goldstone is ignored, the agreement among the various investigators is remarkable, especially in the light of the differing techniques and satellites used.

Table 4 shows the simple longitude differences between JPL and GSFC/SAO/NWL derived positions. Here we note the 2nd inconsistency between satellite and DSS solutions. In each case the satellite solutions are rotated with respect to the DSS longitudes, but the GSFC and DSS longitudes for Tidbinbilla (4742) are inconsistent by about $0''\!.4$ from the mean difference of the other three. In contrast, the NWL solution shows no inconsistency. Since the GSFC solution for Orroral alone shows a substantial inconsistency it is possible that survey error is

Table 3

Comparison of Distances from the Earth's Spin Axis Between JPL and GSFC, SAO, NWL Inferred Solutions

Deep Space Station Name	Deep Space Station Number	GSFC	SAO*	NWL
Goldstone	4712	-3.8	6.2	-32.2
Woomera	4741	0.2	-6.3	6.1
Tidbinbilla	4742	2.0	—	0.5
Johannesburg	4751	0.7	-7.0	—

(NWL/GSFC/SAO) - JPL[1] (LS25 Solutions) in Meters

*These values differ from those quoted in [3] because Gaposchkin and Lambeck did not use the local survey coordinates quoted in [9] for the JPL sites.

Table 4

Longitude Differences ($\Delta\lambda$) in Seconds of Arc (.03" ~ 1 meter)
JPL - (GSFC/SAO/NWL)

Deep Space Station		GSFC		SAO		NWL	
Name	Number	$\Delta\lambda_i$	$(\overline{\Delta\lambda}-\Delta\lambda_i)$*	$\Delta\lambda_i$	$(\overline{\Delta\lambda}-\Delta\lambda_i)$	$\Delta\lambda_i$	$(\overline{\Delta\lambda}-\Delta\lambda_i)$
Goldstone	4712	0.81	-0.03	1.04	-0.29	1.84	-0.17
Woomera	4741	0.79	-0.01	0.59	0.16	1.53	0.14
Tidbinbilla	4742	0.33	—	—	—	1.66	0.01
Johannesburg	4751	0.75	0.03	0.63	0.12	—	

*where $\overline{\Delta\lambda}$ is the mean longitude difference.
Tidbinbilla has been excluded from the mean longitude difference calculation for GSFC.
$\overline{\Delta\lambda}$ = 0.78 GSFC, 0.75 SAO, 1.67 NWL

responsible for the discrepancy. The observed discrepancy in longitude of 0″.4 is still rather small, being equivalent to only a little more than 10m. The mean rotation between JPL and GSFC longitudes for Goldstone, Johannesburg and Woomera is 0″.78. None of the three deviates from this mean by more than 0″.03. The SAO mean rotation is almost the same (0″.75) but the scatter is far greater. Both SAO and ourselves used optical data for the derivation of these positions. But the SAO results were obtained simultaneously with the gravity field in long (up to 30 day) multiple arc solutions. In contrast, we were able to use short (2 day) arc solutions in which model error does not build up excessively. The GEOS flash data are so numerous that long arcs are not necessary to secure a significant amount of data.

Table 5 compares the surveyed and satellite derived longitude differences for the stations on the AGD in the vicinity of Orroral and Woomera. The last column, giving the difference between satellite and surveyed longitudes, is essentially the slope, in longitude, of the Australian Geodetic Datum with respect to the center-of-mass datums between the stations. Discounting the GSFC Orroral site value the agreement is very good. Fisher[7] obtains a value of about 0″.2 for this difference.

3. PROPOSED DSS SITE COORDINATES

Tables 6 and 6.1 give new values for center-of-mass DSS coordinates at Goldstone (4712), Woomera (4741) and Johannesburg (4751). The values were derived from coordinates for nearby optical sites obtained by GSFC.[2] Tables 7 and 7.1 give the GSFC values corrected for the observed longitude differences. Tables 8 and 8.1 give the coordinates obtained by combining

Table 5

Comparison of Australian Longitude Differences

Survey Vs. JPL, GSFC, and NWL

Solution	Stations	Surveyed Differences	Derived Solutions	Survey - JPL/GSFC/NWL
JPL-LS24	4742-4741	12°.09391166	12°.0937640	0".53
JPL-LS25	4742-4741	12°.09391166	12°.0937940	0".42
GSFC	1038-9023	12°.07546918	12°.0754775	-0".03
NWL	749-743	12°.10413055	12°.1039777	0".55

Table 6

Derived Center of Mass Coordinates for DSS Stations*

Station	Geodetic Latitude	Geodetic Longitude (E)	Height (m)
4712	35°17'59".67	243°11'39".61	936.
4741	-31°22'55".25	136°53'14".24	148.
4742	Not given because of suspected survey error		
4751	-25°53'23".73	27°41'06".81	1410.

Table 7

Derived Center of Mass Coordinates for DSS Stations Corrected for Longitude Differences*

Station	Geodetic Latitude	Geodetic Longitude (E)	Height (m)
4712	35°17'59".67	243°11'40".42	936.
4741	-31°22'55".25	136°53'15".03	148.
4742	-35°24'03".22	148°58'52".68	673.
4751	-25°53'23".73	27°41'07".56	1410.

Table 8

Derived Center of Mass Coordinates for DSS Stations Based Upon GSFC Z and JPL X and Y Rectangular Coordinates*

Station	Geodetic Latitude	Geodetic Longitude (E)	Height (m)
4712	35°17'59".59	243°11'40".41	939.
4741	-31°22'55".24	136°53'15".03	149.
4742	-35°24'03".26	148°58'52".68	672.
4751	-25°53'23".74	27°41'07".56	1409.

*Referred to an ellipsoid with the parameters: Semi-major axis = 6378155 meters
1/flattening = 298.255

Table 6.1

Derived Center of Mass Coordinates for DSS Stations

Station	X (m)	Y (m)	Z (m)
4712	-2350456.	-4651969.	3665623.
4741	-3978702.	3724860.	-3302212.
4742	Not given because of suspected survey error		
4751	5085453.	2668250.	-2768719.

Table 7.1

Derived Center of Mass Coordinates for DSS Stations
Corrected for Longitude Differences

Station	X (m)	Y (m)	Z (m)
4712	-2350438.	-4651979.	3665623.
4741	-3978717.	3724845.	-3302212.
4742	-4460982.	2682411.	-3674611.
4751	5085443.	2668268.	-2768719.

Table 8.1

Derived Center of Mass Coordinates for DSS Stations Based Upon
GSFC Z and JPL X and Y Rectangular Coordinates

Station	X (m)	Y (m)	Z (m)
4712	-2350440.	-4651982.	3665623.
4741	-3978717.	3724845.	-3302212.
4742	-4460981.	2682410.	-3674611.
4751	5085442.	2668268.	-2768719.

the JPL-derived (LS25 solution) values for X and Y and with the GSFC[2] Z-values.

4. CONCLUSIONS

In conclusion we feel that it is very encouraging to see that the satellite geodesy results of four independent investigators agree to 10 meters or better after systematic differences such as longitude rotations are removed. This is especially important when one considers that the computer programs, techniques and in some cases even the satellites were different.

The preceding comparisons show that the GEOS I and II optical flash system data have yielded results equal or superior to other systems.

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